Army Research Laboratory

High-Strain Rate Mechanical Response of Green Insensitive Munitions Gun Propellants

by Michael G. Leadore

ARL-TR-2755 June 2002

Army Research Laboratory
Aberdeen Proving Ground, MD 21005-5069

ARL-TR-2755 **June 2002**

High-Strain Rate Mechanical Response of Green Insensitive Munitions Gun Propellants

Michael G. Leadore
Weapons and Materials Research Directorate, ARL

Abstract

Four lots of green insensitive munitions gun propellants were tested in uniaxial compression. A production lot of M14 that is currently used in the M865 training round was also tested for comparison purposes. The materials were tested while conditioned at 21°, 63°, and -32 °C. The materials were taken to ~60% strain using a deformation rate of 1.3 m/s. The stress at failure, strain at failure, compressive modulus, failure modulus, incremental energy density, and the fracture assessment values were recorded for each test.

Contents

INTENTIONALLY LEFT BLANK.

List of Figures

INTENTIONALLY LEFT BLANK.

List of Tables

INTENTIONALLY LEFT BLANK.

1. Introduction

The subject of this report is the material test systems servo-hydraulic tester high-rate mechanical response of Alliant Tech Systems M865 gun propellants (Figure 1). Four lots were designed as RPD-441, RPD-442, RPD-443A, and RPD-443B. The Radford manufactured materials were a part of the Green Insensitive Munitions Program (test sets 21–31, FY 02). For comparative purposes, a production lot of M14, lot no. HCL95C025003, was also tested using similar test conditions.

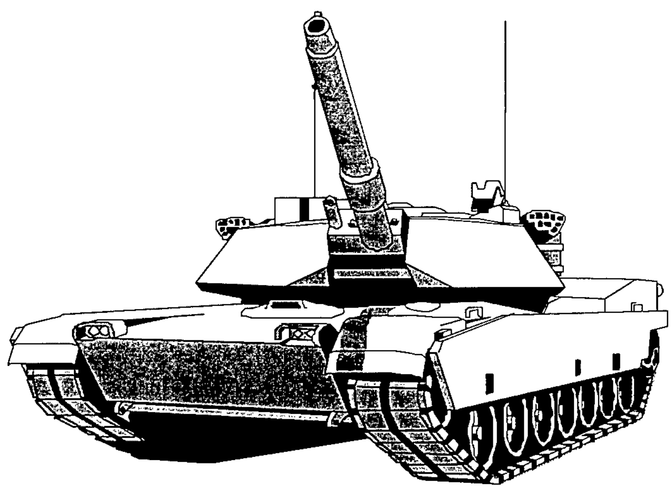

Figure 1. M1 Abrams with 120-mm cannon.

2. Background

Four lots of Radford manufactured gun propellants (Figure 2) were received from Alliant Tech Systems of the Radford Army Ammunition Plant. Note the rough and somewhat deformed grain surfaces from lot RPD-443A. Lots RPD-441 and RPD-442 were solventless formulations, and lots RPD-443A and RPD-443B were manufactured using solvent. The high-energy propellants were manufactured in a mixer and extruded thermally into a granular configuration. The granular material had a diameter of ~6.3 mm. Several grains from each lot of experimental gun propellants were shipped to Dr. Robert Lieb of the U.S. Army Research Laboratory, Aberdeen Proving Ground (APG), MD. Also, a production lot of Radford manufactured M14 granular propellant was procured from APG for comparison testing. All of these materials were tested during December 2001 for high-rate uniaxial compression mechanical response evaluation.

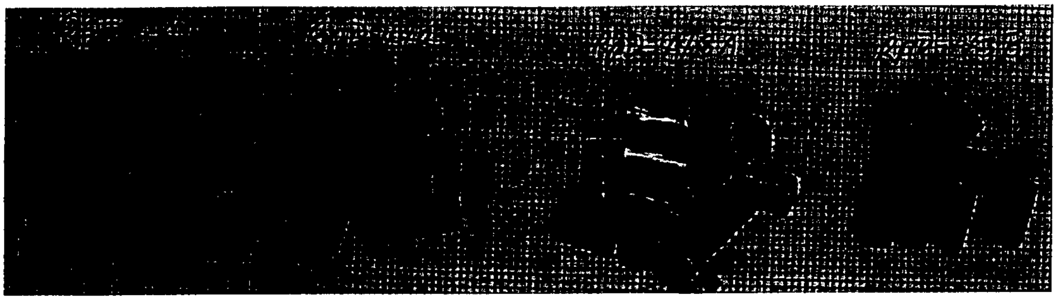

Figure 2. Green insensitive munitions propellant lots of gun as received. (Note rough surfaces and irregular shaped grains for lot RPD-443A.)

3. Approach and Results

The RPD-441, RPD-442, RPD-443A, and RPD-443B propellant lots were received in granular form. The lots were cut into test specimens having a length-to-diameter ratio of 1.06. Specimen preparation was accomplished using an Isomet low-speed diamond bladed saw. Sample ends were machined so that the surfaces were flat, parallel to each other, and perpendicular to the extruded axis. The M14 lot was also granular, with a diameter of 6.60 mm, and was also cut using an Isomet diamond saw.

Material test systems servo hydraulic tester mechanical properties tests [1–7] (Figure 3) were conducted on several specimens under each test condition. Strain rates of 130.0 s^{-1} were achieved. The specimens were taken to failure at ambient pressure to ~50% end strain while conditioned at 21°, 63°, and −32 °C. The stress at failure, strain at failure, the modulus, failure modulus, the incremental energy density, and the fracture assessment value were recorded for each test, and the average values are listed in Table 1.

Figure 3. Preparing to test energetic material using high-rate load frame.

Table 1. Mechanical properties of Radford manufactured green insensitive munitions propellant lots at 21°, 63°, and -32 °C.

Lot	Stress at Failure (MPa)	Strain at Failure (%)	Modulus (GPa)	Failure Modulus[a] (GPa)	IED[b] (MPa)	FAV[c] (MPa)
at 21 °C						
RPD-441 Lot 01K071870	14.10	4.30	0.611	0.110	10.10	1AB
RPD-442 Lot 01K071867	16.12	6.15	0.402	0.131	5.62	1AB
RPD-443A Lot 01K071868	97.08	10.01	1.21	-0.0691	18.72	4AS
RPD-443B Lot 01K071869	91.17	8.36	1.54	-0.0950	18.90	4AS
M14 Lot 95C025003	104.80	4.16	2.94	-0.0833	17.47	3AS
at 63 °C						
RPD-441 Lot 01K071870	11.21	6.30	0.182	0.059	3.54	1AB
RPD-442 Lot 01K071867	12.02	6.55	0.762	0.056	3.35	1AB
RPD-443A Lot 01K071868	64.74	9.22	0.901	-0.032	13.23	2AS
RPD-443B Lot 01K071869	63.07	9.64	1.27	-0.086	12.37	2AS
M14 Lot 95C025003	76.58	3.72	2.40	-0.081	16.17	3AS
at -32 °C						
RPD-441 Lot 01K071870	52.36	7.25	1.37	0.088	14.20	3A
RPD-442 Lot 01K071867	64.20	5.50	1.36	0.271	19.44	3A
RPD-443A Lot 01K071868	92.04	8.60	1.26	-2.48	6.20	8AS
RPD-443B Lot 01K071869	99.29	8.54	1.50	-3.26	7.67	8AS
M14 Lot 95C025003	154.20	4.33	3.63	-0.491	6.78	6AS

[a]The failure modulus (slope of the curve after failure) has been added. Generally, the lower the value, the worse the material (i.e., a negative value indicates that the material is unable to sustain load). A positive value indicates a positive failure slope (i.e., the material is better able to support load after failure).

[b]The incremental energy density (IED) value reported is the amount of energy per unit volume absorbed at 25% strain; this includes a portion of the area located beneath the stress/strain curve.

[c]The tested specimens were assigned a fracture assessment value (FAV). The values range from 0 (no observed fracturing) through 9 (severe fracturing observed). The type of fracture was also characterized using the following methodology: A = axial fracture, S = shear fracture, B = barreling/deformation, and R = radial splitting (i.e., 8AS indicates the tested specimens showed a severe amount of axial fracture).

4. Conclusions

Four lots of Radford manufactured high-energy gun propellants (Figure 2) and a production lot of M14 were tested for mechanical response evaluation at ambient pressure while conditioned at 21°, 63°, and –32 °C. The materials were tested in uniaxial compression to ~50% end strain using a deformation rate of 1.33 m/s.

At 21 °C, RPD-441, RPD-442, RPD-443A, RPD-443B, and the M14 lots all showed good response to uniaxial compression. The positive failure modulus values achieved indicated the lots' abilities to sustain load beyond ~50% strain. Note that the stress vs. strain plot (Figure 4) shows RPD-441 and RPD-442 lots work hardening beyond 40% strain. The tested specimens (Figure 5) suffered permanent deformation with very minimal fracturing.

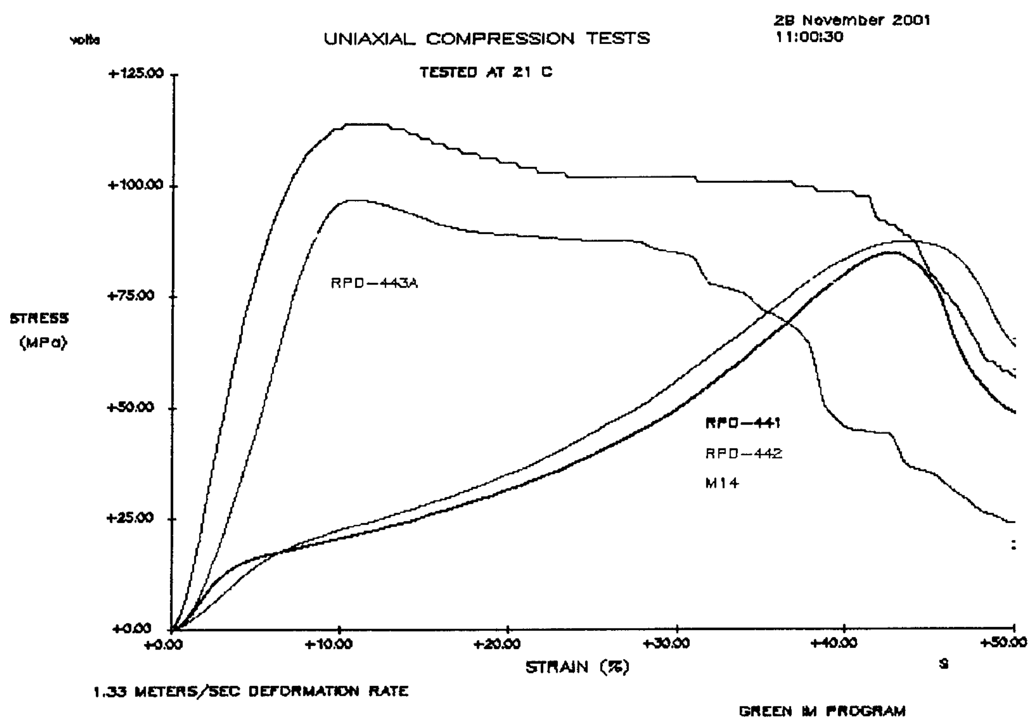

Figure 4. Stress vs. strain plot of green insensitive munitions propellant lots tested at 21 °C.

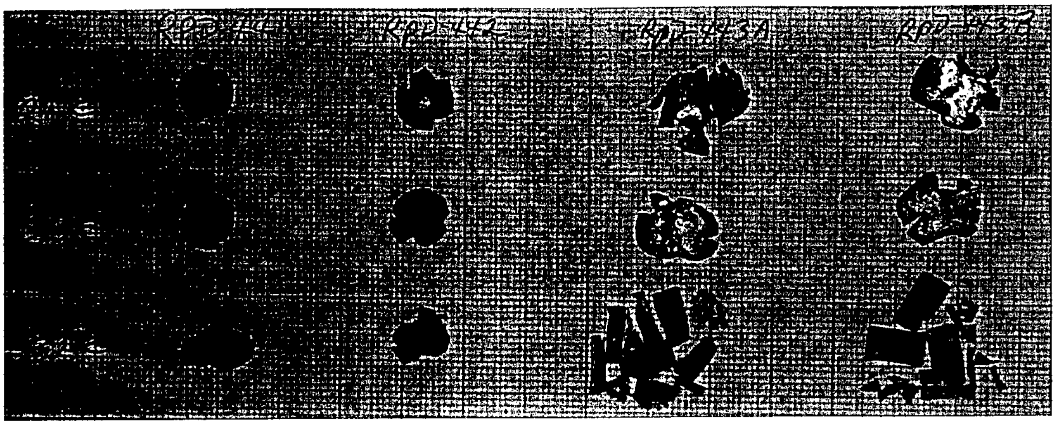

Figure 5. Remains of specimens tested at 21°, 63°, and -32 °C.

At 63 °C, again, the mechanical response of all the lots was quite good. The Young's modulus values showed some "softening" as a result of the higher testing temperature; this would be expected. The stress/strain plot (Figure 6) shows that all the lots were capable of sustaining load. The tested specimens (Figure 5) again showed minimal axial fracture and deformation.

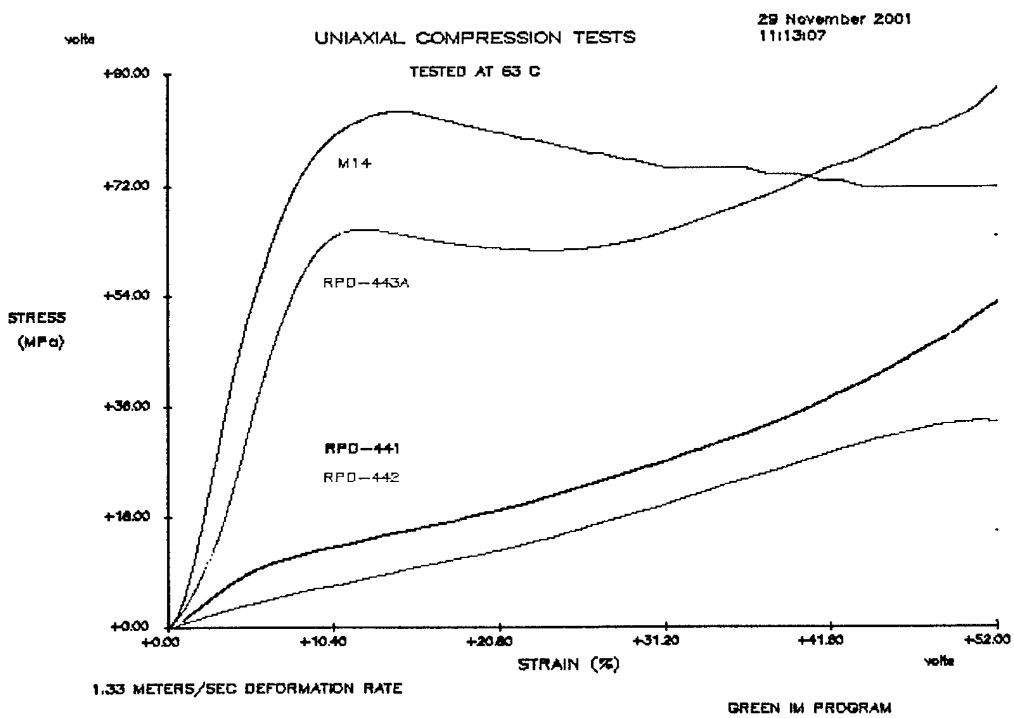

Figure 6. Stress vs. strain plot of green insensitive munitions propellant lots tested at 63 °C.

At -32 °C, the solventless produced lots RPD-441 and RPD-442 showed a far superior response to uniaxial compression than the other lots tested. The tested specimens (Figure 5) suffered only minimal amounts of axial and shear fracture, and the core area of the tested specimens remained mostly whole. Note that the stress/strain plot at -32 °C (Figure 7) shows that lots RPD-441 and RPD-442 are capable of sustaining load and work hardening beyond 40% strain and, thus, were the only lots yielding positive failure modulus values. Lots RPD-443A and RPD-443B showed very poor responses to mechanical testing at -32 °C. The failure modulus values for RPD-443A and RPD-443B at -32 °C were particularly disturbing and indicated these materials lacked any mechanical integrity. The tested remains from these lots showed much axial and shear fracture. This amount and type of fracturing observed would likely increase the surface area of these materials significantly and, thus, increase the burn rate of the material.

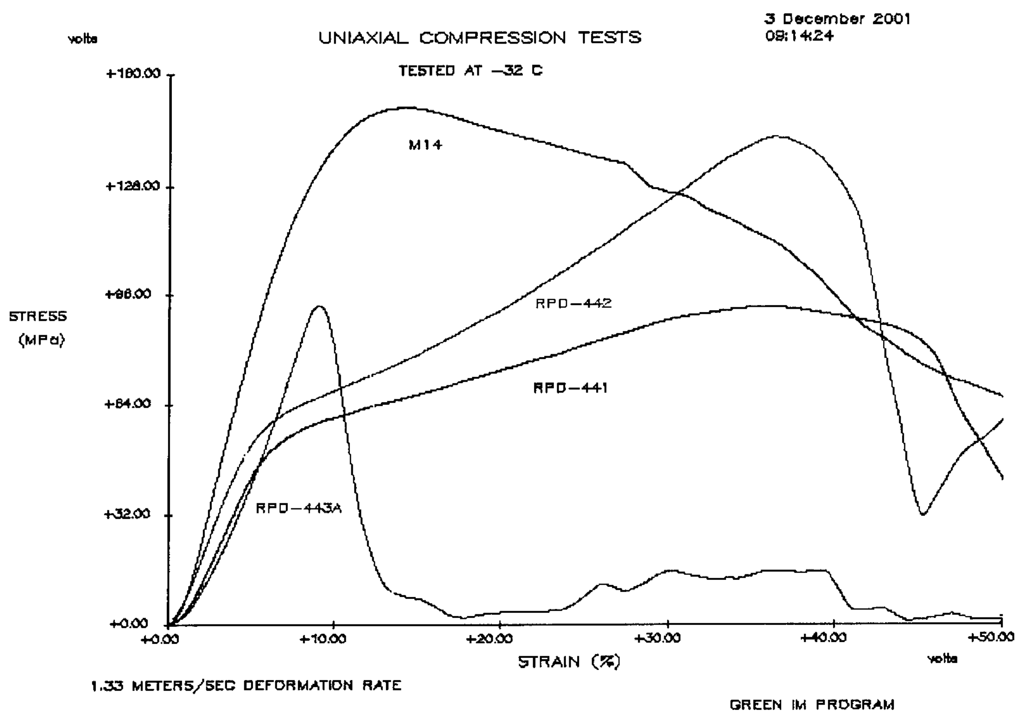

Figure 7. Stress vs. strain plot of green insensitive munitions propellant lots tested at -32 °C.

Overall, all the materials' mechanical responses at 21° and 63 °C were quite good. At -32 °C, the RPD-441 and RPD-442 lots were clearly the better materials, followed by the M14 lot, and finally the solvent produced lots RPD-443A and RPD-443B, which suffered prolific fracture at -32 °C.

5. References

1. Gazonas, G. A. "The Mechanical Response of M30, XM39, and JA2 Propellants at Strain Rates From 10^{-2} to 250 sec^{-1}." BRL-TR-3181, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, January 1991.

2. Lieb, R. J. "Impact-Generated Surface Area in Gun Propellant." BRL-TR-2946, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, November 1988.

3. Lieb, R. J., and J. J. Rocchio. "High Strain Rate Mechanical Properties Testing on Lots of Solid Gun Propellant With Deviant Interior Ballistic Performance." *1982 JANNAF Structures and Mechanical Behavior Subcommittee Meeting*, CPIA Publication 368, pp. 23–38, October 1982.

4. Leadore, M. G. "MTS Servo-Hydraulic Tester (SHT) Mechanical Properties Evaluation of M43 Propellants." ARL-TN-5, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD, March 1993.

5. Leadore, M. G., and C. J. Gillich. "Material Testing System (MTS) Servo-Hydraulic Tester (SHT) Mechanical Response of Energetic Thermal Plastic Elastomer (ETPE) RDX Based Propellants." ARL-TN-28, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD, April 1994.

6. Leadore, M. G. "Mechanical Response of Energetic Thermoplastic Elastomer Low-Vulnerability Ammunition (ETPE-LOVA RDX-Based, TNAZ-Based, and CL-20-Based Gun Propellants." ARL-TN-64, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD, March 1996.

7. Lieb, R. J. Personal communication. U.S. Army Research Laboratory, Aberdeen Proving Ground, MD, December 2001.

INTENTIONALLY LEFT BLANK.

NO. OF COPIES	ORGANIZATION
2	DEFENSE TECHNICAL INFORMATION CENTER DTIC OCA 8725 JOHN J KINGMAN RD STE 0944 FT BELVOIR VA 22060-6218
1	HQDA DAMO FDT 400 ARMY PENTAGON WASHINGTON DC 20310-0460
1	OSD OUSD(A&T)/ODDR&E(R) DR R J TREW 3800 DEFENSE PENTAGON WASHINGTON DC 20301-3800
1	COMMANDING GENERAL US ARMY MATERIEL CMD AMCRDA TF 5001 EISENHOWER AVE ALEXANDRIA VA 22333-0001
1	INST FOR ADVNCD TCHNLGY THE UNIV OF TEXAS AT AUSTIN 3925 W BRAKER LN STE 400 AUSTIN TX 78759-5316
1	US MILITARY ACADEMY MATH SCI CTR EXCELLENCE MADN MATH THAYER HALL WEST POINT NY 10996-1786
1	DIRECTOR US ARMY RESEARCH LAB AMSRL D DR D SMITH 2800 POWDER MILL RD ADELPHI MD 20783-1197
1	DIRECTOR US ARMY RESEARCH LAB AMSRL CI AI R 2800 POWDER MILL RD ADELPHI MD 20783-1197

NO. OF COPIES	ORGANIZATION
3	DIRECTOR US ARMY RESEARCH LAB AMSRL CI LL 2800 POWDER MILL RD ADELPHI MD 20783-1197
3	DIRECTOR US ARMY RESEARCH LAB AMSRL CI IS T 2800 POWDER MILL RD ADELPHI MD 20783-1197

ABERDEEN PROVING GROUND

NO. OF COPIES	ORGANIZATION
2	DIR USARL AMSRL CI LP (BLDG 305)

NO. OF COPIES	ORGANIZATION
1	DIRECTOR US ARMY RESEARCH LAB AMSRL CP CA D SNIDER 2800 POWDER MILL RD ADELPHI MD 20783-1197
1	DIRECTOR US ARMY RESEARCH LAB AMSRL CI IS R 2800 POWDER MILL RD ADELPHI MD 20783-1197
3	DIRECTOR US ARMY RESEARCH LAB AMSRL OP SD TL 2800 POWDER MILL RD ADELPHI MD 20783-1197
1	DIRECTOR US ARMY RESEARCH LAB AMSRL SS SD H WALLACE 2800 POWDER MILL RD ADELPHI MD 20783-1197
2	DIRECTOR US ARMY RESEARCH LAB AMSRL SS SE DS R REYZER R ATKINSON 2800 POWDER MILL RD ADELPHI MD 20783-1197
1	DIRECTOR US ARMY RESEARCH LAB AMSRL WM MB A FRYDMAN 2800 POWDER MILL RD ADELPHI MD 20783-1197
1	DPTY ASST SECY FOR R&T SARD TT THE PENTAGON RM 3EA79 WASHINGTON DC 20301-7100
1	COMMANDER US ARMY MATERIEL CMD AMXMI INT 5001 EISENHOWER AVE ALEXANDRIA VA 22333-0001

NO. OF COPIES	ORGANIZATION
4	COMMANDER US ARMY ARDEC AMSTA AR CC G PAYNE J GEHBAUER C BAULIEU H OPAT PICATINNY ARSENAL NJ 07806-5000
2	COMMANDER US ARMY ARDEC AMSTA AR AE WW E BAKER J PEARSON PICATINNY ARSENAL NJ 07806-5000
1	COMMANDER US ARMY ARDEC AMSTA AR FSE PICATINNY ARSENAL NJ 07806-5000
1	COMMANDER US ARMY ARDEC AMSTA AR TD C SPINELLI PICATINNY ARSENAL NJ 07806-5000
6	COMMANDER US ARMY ARDEC AMSTA AR CCH A W ANDREWS S MUSALLI R CARR M LUCIANO E LOGSDEN T LOUZEIRO PICATINNY ARSENAL NJ 07806-5000
1	COMMANDER US ARMY ARDEC AMSTA AR CCH P J LUTZ PICATINNY ARSENAL NJ 07806-5000

NO. OF COPIES	ORGANIZATION
1	COMMANDER US ARMY ARDEC AMSTA AR FSF T C LIVECCHIA PICATINNY ARSENAL NJ 07806-5000
1	COMMANDER US ARMY ARDEC AMSTA ASF PICATINNY ARSENAL NJ 07806-5000
1	COMMANDER US ARMY ARDEC AMSTA AR QAC T C C PATEL PICATINNY ARSENAL NJ 07806-5000
1	COMMANDER US ARMY ARDEC AMSTA AR M D DEMELLA PICATINNY ARSENAL NJ 07806-5000
3	COMMANDER US ARMY ARDEC AMSTA AR FSA A WARNASH B MACHAK M CHIEFA PICATINNY ARSENAL NJ 07806-5000
2	COMMANDER US ARMY ARDEC AMSTA AR FSP G M SCHIKSNIS D CARLUCCI PICATINNY ARSENAL NJ 07806-5000
2	COMMANDER US ARMY ARDEC AMSTA AR CCH C H CHANIN S CHICO PICATINNY ARSENAL NJ 07806-5000

NO. OF COPIES	ORGANIZATION
1	COMMANDER US ARMY ARDEC AMSTA AR QAC T D RIGOGLIOSO PICATINNY ARSENAL NJ 07806-5000
1	COMMANDER US ARMY ARDEC AMSTA AR WET T SACHAR BLDG 172 PICATINNY ARSENAL NJ 07806-5000
1	US ARMY ARDEC INTELLIGENCE SPECIALIST AMSTA AR WEL F M GUERRIERE PICATINNY ARSENAL NJ 07806-5000
9	COMMANDER US ARMY ARDEC AMSTA AR CCH B P DONADIA F DONLON P VALENTI C KNUTSON G EUSTICE S PATEL G WAGNECZ R SAYER F CHANG PICATINNY ARSENAL NJ 07806-5000
6	COMMANDER US ARMY ARDEC AMSTA AR CCL F PUZYCKI R MCHUGH D CONWAY E JAROSZEWSKI R SCHLENNER M CLUNE PICATINNY ARSENAL NJ 07806-5000

NO. OF COPIES	ORGANIZATION
1	PM ARMS SFAE GCSS ARMS BLDG 171 PICATINNY ARSENAL NJ 07806-5000
1	COMMANDER US ARMY ARDEC AMSTA AR WEA J BRESCIA PICATINNY ARSENAL NJ 07806-5000
12	PM TMAS SFAE GSSC TMA R MORRIS C KIMKER D GUZIEWICZ E KOPACZ R ROESER R DARCY R KOWALSKI R MCDANOLDS L D ULISSE C ROLLER J MCGREEN B PATTER PICATINNY ARSENAL NJ 07806-5000
1	COMMANDER US ARMY ARDEC PRODUCTION BASE MODERN ACTY AMSMC PBM K PICATINNY ARSENAL NJ 07806-5000
1	COMMANDER US ARMY TACOM PM ABRAMS SFAE ASM AB 6501 ELEVEN MILE RD WARREN MI 48397-5000

NO. OF COPIES	ORGANIZATION
1	COMMANDER US ARMY TACOM AMSTA SF WARREN MI 48397-5000
1	COMMANDER US ARMY TACOM PM BFVS SFAE GCSS W BV 6501 ELEVEN MILE RD WARREN MI 48397-5000
1	DIRECTOR AIR FORCE RESEARCH LAB MLLMD D MIRACLE 2230 TENTH ST WRIGHT PATTERSON AFB OH 45433-7817
1	OFC OF NAVAL RESEARCH J CHRISTODOULOU ONR CODE 332 800 N QUINCY ST ARLINGTON VA 22217-5600
1	US ARMY CERL R LAMPO 2902 NEWMARK DR CHAMPAIGN IL 61822
1	COMMANDER US ARMY TACOM PM SURVIVABLE SYSTEMS SFAE GCSS W GSI H M RYZYI 6501 ELEVEN MILE RD WARREN MI 48397-5000
1	COMMANDER US ARMY TACOM CHIEF ABRAMS TESTING SFAE GCSS W AB QT T KRASKIEWICZ 6501 ELEVEN MILE RD WARREN MI 48397-5000

NO. OF COPIES	ORGANIZATION
1	COMMANDER WATERVLIET ARSENAL SMCWV QAE Q B VANINA BLDG 44 WATERVLIET NY 12189-4050
3	ARMOR SCHOOL ATZK TD R BAUEN J BERG A POMEY FT KNOX KY 40121
2	HQ IOC TANK AMMUNITION TEAM AMSIO SMT R CRAWFORD W HARRIS ROCK ISLAND IL 61299-6000
2	COMMANDER US ARMY AMCOM AVIATION APPLIED TECH DIR J SCHUCK FT EUSTIS VA 23604-5577
14	COMMANDER US ARMY TACOM AMSTA TR R R MCCLELLAND D THOMAS J BENNETT D HANSEN AMSTA JSK S GOODMAN J FLORENCE K IYER D TEMPLETON A SCHUMACHER AMSTA TR D D OSTBERG L HINOJOSA B RAJU AMSTA CS SF H HUTCHINSON F SCHWARZ WARREN MI 48397-5000

NO. OF COPIES	ORGANIZATION
14	BENET LABORATORIES AMSTA AR CCB R FISCELLA M SOJA E KATHE M SCAVULO G SPENCER P WHEELER S KRUPSKI J VASILAKIS G FRIAR R HASENBEIN AMSTA CCB R S SOPOK E HYLAND D CRAYON R DILLON WATERVLIET NY 12189-4050
1	DIRECTOR US ARMY AMCOM SFAE AV RAM TV D CALDWELL BLDG 5300 REDSTONE ARSENAL AL 35898
1	NAVAL SURFACE WARFARE CTR DAHLGREN DIV CODE G06 DAHLGREN VA 22448
2	US ARMY CORPS OF ENGINEERS CERD C T LIU CEW ET T TAN 20 MASS AVE NW WASHINGTON DC 20314
1	US ARMY COLD REGIONS RSCH & ENGRNG LAB P DUTTA 72 LYME RD HANOVER NH 03755
1	USA SBCCOM PM SOLDIER SPT AMSSB PM RSS A J CONNORS KANSAS ST NATICK MA 01760-5057

NO. OF COPIES	ORGANIZATION
2	USA SBCCOM MATERIAL SCIENCE TEAM AMSSB RSS J HERBERT M SENNETT KANSAS ST NATICK MA 01760-5057
2	OFC OF NAVAL RESEARCH D SIEGEL CODE 351 J KELLY 800 N QUINCY ST ARLINGTON VA 22217-5660
1	NAVAL SURFACE WARFARE CTR TECH LIBRARY CODE 323 17320 DAHLGREN RD DAHLGREN VA 22448
1	NAVAL SURFACE WARFARE CTR CRANE DIVISION M JOHNSON CODE 20H4 LOUISVILLE KY 40214-5245
2	NAVAL SURFACE WARFARE CTR U SORATHIA C WILLIAMS CD 6551 9500 MACARTHUR BLVD WEST BETHESDA MD 20817
2	COMMANDER NAVAL SURFACE WARFARE CTR CARDEROCK DIVISION R PETERSON CODE 2020 M CRITCHFIELD CODE 1730 BETHESDA MD 20084
8	DIRECTOR US ARMY NATIONAL GROUND INTELLIGENCE CTR D LEITER MS 404 M HOLTUS MS 301 M WOLFE MS 307 S MINGLEDORF MS 504 J GASTON MS 301 W GSTATTENBAUER MS 304 R WARNER MS 305 J CRIDER MS 306 220 SEVENTH ST NE CHARLOTTESVILLE VA 22091

NO. OF COPIES	ORGANIZATION
1	NAVAL SEA SYSTEMS CMD D LIESE 2531 JEFFERSON DAVIS HWY ARLINGTON VA 22242-5160
1	NAVAL SURFACE WARFARE CTR M LACY CODE B02 17320 DAHLGREN RD DAHLGREN VA 22448
1	EXPEDITIONARY WARFARE DIV N85 F SHOUP 2000 NAVY PENTAGON WASHINGTON DC 20350-2000
8	US ARMY SBCCOM SOLDIER SYSTEMS CENTER BALLISTICS TEAM J WARD W ZUKAS P CUNNIFF J SONG MARINE CORPS TEAM J MACKIEWICZ BUS AREA ADVOCACY TEAM W HASKELL AMSSB RCP SS W NYKVIST S BEAUDOIN KANSAS ST NATICK MA 01760-5019
7	US ARMY RESEARCH OFC A CROWSON H EVERETT J PRATER G ANDERSON D STEPP D KISEROW J CHANG PO BOX 12211 RESEARCH TRIANGLE PARK NC 27709-2211
1	AFRL MLBC 2941 P ST RM 136 WRIGHT PATTERSON AFB OH 45433-7750

NO. OF COPIES	ORGANIZATION
8	NAVAL SURFACE WARFARE CTR J FRANCIS CODE G30 D WILSON CODE G32 R D COOPER CODE G32 J FRAYSSE CODE G33 E ROWE CODE G33 T DURAN CODE G33 L DE SIMONE CODE G33 R HUBBARD CODE G33 DAHLGREN VA 22448
2	NAVAL SURFACE WARFARE CTR CARDEROCK DIVISION R CRANE CODE 2802 C WILLIAMS CODE 6553 3A LEGGETT CIR BETHESDA MD 20054-5000
1	AFRL MLSS R THOMSON 2179 12TH ST RM 122 WRIGHT PATTERSON AFB OH 45433-7718
2	AFRL F ABRAMS J BROWN BLDG 653 2977 P ST STE 6 WRIGHT PATTERSON AFB OH 45433-7739
5	DIRECTOR LLNL R CHRISTENSEN S DETERESA F MAGNESS M FINGER MS 313 M MURPHY L 282 PO BOX 808 LIVERMORE CA 94550
1	AFRL MLS OL L COULTER 5851 F AVE BLDG 849 RM AD1A HILL AFB UT 84056-5713

NO. OF COPIES	ORGANIZATION
1	DIRECTOR LOS ALAMOS NATIONAL LAB F L ADDESSIO T 3 MS 5000 PO BOX 1633 LOS ALAMOS NM 87545
1	OSD JOINT CCD TEST FORCE OSD JCCD R WILLIAMS 3909 HALLS FERRY RD VICKSBURG MS 29180-6199
3	DARPA M VANFOSSEN S WAX L CHRISTODOULOU 3701 N FAIRFAX DR ARLINGTON VA 22203-1714
2	SERDP PROGRAM OFC PM P2 C PELLERIN B SMITH 901 N STUART ST STE 303 ARLINGTON VA 22203
1	OAK RIDGE NATIONAL LABORATORY R M DAVIS PO BOX 2008 OAK RIDGE TN 37831-6195
1	OAK RIDGE NATIONAL LABORATORY C EBERLE MS 8048 PO BOX 2008 OAK RIDGE TN 37831
3	DIRECTOR SANDIA NATIONAL LABS APPLIED MECHANICS DEPT MS 9042 J HANDROCK Y R KAN J LAUFFER PO BOX 969 LIVERMORE CA 94551-0969

NO. OF COPIES	ORGANIZATION
1	OAK RIDGE NATIONAL LABORATORY C D WARREN MS 8039 PO BOX 2008 OAK RIDGE TN 37831
4	NIST M VANLANDINGHAM MS 8621 J CHIN MS 8621 J MARTIN MS 8621 D DUTHINH MS 8611 100 BUREAU DR GAITHERSBURG MD 20899
1	HYDROGEOLOGIC INC SERDP ESTCP SPT OFC S WALSH 1155 HERNDON PKWY STE 900 HERNDON VA 20170
3	NASA LANGLEY RSCH CTR AMSRL VS W ELBER MS 266 F BARTLETT JR MS 266 G FARLEY MS 266 HAMPTON VA 23681-0001
1	NASA LANGLEY RSCH CTR T GATES MS 188E HAMPTON VA 23661-3400
1	FHWA E MUNLEY 6300 GEORGETOWN PIKE MCLEAN VA 22101
1	USDOT FEDERAL RAILRD M FATEH RDV 31 WASHINGTON DC 20590
3	CYTEC FIBERITE R DUNNE D KOHLI R MAYHEW 1300 REVOLUTION ST HAVRE DE GRACE MD 21078
1	MARINE CORPS INTLLGNC ACTVTY D KOSITZKE 3300 RUSSELL RD STE 250 QUANTICO VA 22134-5011

NO. OF COPIES	ORGANIZATION
1	DIRECTOR NATIONAL GRND INTLLGNC CTR IANG TMT 220 SEVENTH ST NE CHARLOTTESVILLE VA 22902-5396
1	SIOUX MFG B KRIEL PO BOX 400 FT TOTTEN ND 58335
2	3TEX CORPORATION A BOGDANOVICH J SINGLETARY 109 MACKENAN DR CARY NC 27511
1	3M CORPORATION J SKILDUM 3M CENTER BLDG 60 IN 01 ST PAUL MN 55144-1000
1	DIRECTOR DEFENSE INTLLGNC AGNCY TA 5 K CRELLING WASHINGTON DC 20310
1	ADVANCED GLASS FIBER YARNS T COLLINS 281 SPRING RUN LANE STE A DOWNINGTON PA 19335
1	COMPOSITE MATERIALS INC D SHORTT 19105 63 AVE NE PO BOX 25 ARLINGTON WA 98223
1	JPS GLASS L CARTER PO BOX 260 SLATER RD SLATER SC 29683
1	COMPOSITE MATERIALS INC R HOLLAND 11 JEWEL CT ORINDA CA 94563

NO. OF COPIES	ORGANIZATION
1	COMPOSITE MATERIALS INC C RILEY 14530 S ANSON AVE SANTA FE SPRINGS CA 90670
2	SIMULA J COLTMAN R HUYETT 10016 S 51ST ST PHOENIX AZ 85044
2	PROTECTION MATERIALS INC M MILLER F CRILLEY 14000 NW 58 CT MIAMI LAKES FL 33014
2	FOSTER MILLER M ROYLANCE W ZUKAS 195 BEAR HILL RD WALTHAM MA 02354-1196
1	ROM DEVELOPMENT CORP R O MEARA 136 SWINEBURNE ROW BRICK MARKET PLACE NEWPORT RI 02840
2	TEXTRON SYSTEMS T FOLTZ M TREASURE 1449 MIDDLESEX ST LOWELL MA 01851
1	O GARA HESS & EISENHARDT M GILLESPIE 9113 LESAINT DR FAIRFIELD OH 45014
2	MILLIKEN RSCH CORP H KUHN M MACLEOD PO BOX 1926 SPARTANBURG SC 29303
1	CONNEAUGHT INDUSTRIES INC J SANTOS PO BOX 1425 COVENTRY RI 02816

NO. OF COPIES	ORGANIZATION
1	BATTELLE NATICK OPNS B HALPIN 209 W CENTRAL ST STE 302 NATICK MA 01760
1	ARMTEC DEFENSE PRODUCTS S DYER 85 901 AVE 53 PO BOX 848 COACHELLA CA 92236
1	NATIONAL COMPOSITE CENTER T CORDELL 2000 COMPOSITE DR KETTERING OH 45420
3	PACIFIC NORTHWEST LAB M SMITH G VAN ARSDALE R SHIPPELL PO BOX 999 RICHLAND WA 99352
2	AMOCO PERFORMANCE PRODUCTS M MICHNO JR J BANISAUKAS 4500 MCGINNIS FERRY RD ALPHARETTA GA 30202-3944
8	ALLIANT TECHSYSTEMS INC C CANDLAND MN11 2830 C AAKHUS MN11 2830 B SEE MN11 2439 N VLAHAKUS MN11 2145 R DOHRN MN11 2830 S HAGLUND MN11 2439 M HISSONG MN11 2830 D KAMDAR MN11 2830 600 SECOND ST NE HOPKINS MN 55343-8367
1	SAIC M PALMER 1410 SPRING HILL RD STE 400 MS SH4 5 MCLEAN VA 22102
1	APPLIED COMPOSITES W GRISCH 333 NORTH SIXTH ST ST CHARLES IL 60174

NO. OF COPIES	ORGANIZATION
1	CUSTOM ANALYTICAL ENG SYS INC A ALEXANDER 13000 TENSOR LANE NE FLINTSTONE MD 21530
1	AAI CORPORATION DR N B MCNELLIS PO BOX 126 HUNT VALLEY MD 21030-0126
1	OFC DEPUTY UNDER SEC DEFNS J THOMPSON 1745 JEFFERSON DAVIS HWY CRYSTAL SQ 4 STE 501 ARLINGTON VA 22202
3	ALLIANT TECHSYSTEMS INC J CONDON E LYNAM J GERHARD WV01 16 STATE RT 956 PO BOX 210 ROCKET CENTER WV 26726-0210
1	PROJECTILE TECHNOLOGY INC 515 GILES ST HAVRE DE GRACE MD 21078
1	HEXCEL INC R BOE PO BOX 18748 SALT LAKE CITY UT 84118
5	AEROJET GEN CORP D PILLASCH T COULTER C FLYNN D RUBAREZUL M GREINER 1100 WEST HOLLYVALE ST AZUSA CA 91702-0296
1	HERCULES INC HERCULES PLAZA WILMINGTON DE 19894
1	BRIGS COMPANY J BACKOFEN 2668 PETERBOROUGH ST HERNDON VA 22071-2443

NO. OF COPIES	ORGANIZATION
1	ZERNOW TECHNICAL SERVICES L ZERNOW 425 W BONITA AVE STE 208 SAN DIMAS CA 91773
1	GENERAL DYNAMICS OTS L WHITMORE 10101 NINTH ST NORTH ST PETERSBURG FL 33702
3	GENERAL DYNAMICS OTS FLINCHBAUGH DIV E STEINER B STEWART T LYNCH PO BOX 127 RED LION PA 17356
1	GKN AEROSPACE D OLDS 15 STERLING DR WALLINGFORD CT 06492
5	SIKORSKY AIRCRAFT G JACARUSO T CARSTENSAN B KAY S GARBO MS S330A J ADELMANN 6900 MAIN ST PO BOX 9729 STRATFORD CT 06497-9729
1	PRATT & WHITNEY C WATSON 400 MAIN ST MS 114 37 EAST HARTFORD CT 06108
1	AEROSPACE CORP G HAWKINS M4 945 2350 E EL SEGUNDO BLVD EL SEGUNDO CA 90245
2	CYTEC FIBERITE M LIN W WEB 1440 N KRAEMER BLVD ANAHEIM CA 92806

NO. OF COPIES	ORGANIZATION
1	UDLP G THOMAS PO BOX 58123 SANTA CLARA CA 95052
2	UDLP R BARRETT MAIL DROP M53 V HORVATICH MAIL DROP M53 328 W BROKAW RD SANTA CLARA CA 95052-0359
3	UDLP GROUND SYSTEMS DIVISION M PEDRAZZI MAIL DROP N09 A LEE MAIL DROP N11 M MACLEAN MAIL DROP N06 1205 COLEMAN AVE SANTA CLARA CA 95052
2	UDLP R BRYNSVOLD P JANKE MS 170 4800 EAST RIVER RD MINNEAPOLIS MN 55421-1498
2	BOEING ROTORCRAFT P MINGURT P HANDEL 800 B PUTNAM BLVD WALLINGFORD PA 19086
1	BOEING DOUGLAS PRODUCTS DIV L J HART SMITH 3855 LAKEWOOD BLVD D800 0019 LONG BEACH CA 90846-0001
1	LOCKHEED MARTIN SKUNK WORKS D FORTNEY 1011 LOCKHEED WAY PALMDALE CA 93599-2502
1	LOCKHEED MARTIN R FIELDS 5537 PGA BLVD SUITE 4516 ORLANDO FL 32839

NO. OF COPIES	ORGANIZATION
1	MATERIALS SCIENCES CORP G FLANAGAN 500 OFC CENTER DR STE 250 FT WASHINGTON PA 19034
1	NORTHRUP GRUMMAN CORP ELECTRONIC SENSORS & SYSTEMS DIV E SCHOCH MS V 16 1745A W NURSERY RD LINTHICUM MD 21090
1	GDLS DIVISION D BARTLE PO BOX 1901 WARREN MI 48090
2	GDLS D REES M PASIK PO BOX 2074 WARREN MI 48090-2074
1	GDLS MUSKEGON OPERATIONS W SOMMERS JR 76 GETTY ST MUSKEGON MI 49442
1	GENERAL DYNAMICS AMPHIBIOUS SYS SURVIVABILITY LEAD G WALKER 991 ANNAPOLIS WAY WOODBRIDGE VA 22191
6	INST FOR ADVANCED TECH H FAIR I MCNAB P SULLIVAN S BLESS W REINECKE C PERSAD 3925 W BRAKER LN STE 400 AUSTIN TX 78759-5316
1	ARROW TECH ASSO 1233 SHELBURNE RD STE D8 SOUTH BURLINGTON VT 05403-7700

NO. OF COPIES	ORGANIZATION
2	CIVIL ENGR RSCH FOUNDATION PRESIDENT H BERNSTEIN R BELLE 1015 15TH ST NW STE 600 WASHINGTON DC 20005
1	R EICHELBERGER CONSULTANT 409 W CATHERINE ST BEL AIR MD 21014-3613
1	G CHRYSSOMALLIS 8500 NORMANDALE LAKE BLVD SUITE 1610 BLOOMINGTON MN 55437-3828
1	UCLA MANE DEPT ENGR IV H T HAHN LOS ANGELES CA 90024-1597
2	UNIV OF DAYTON RESEARCH INST R Y KIM A K ROY 300 COLLEGE PARK AVE DAYTON OH 45469-0168
1	UMASS LOWELL PLASTICS DEPT N SCHOTT 1 UNIVERSITY AVE LOWELL MA 01854
1	IIT RESEARCH CENTER D ROSE 201 MILL ST ROME NY 13440-6916
1	GA TECH RSCH INST GA INST OF TCHNLGY P FRIEDERICH ATLANTA GA 30392
1	MICHIGAN ST UNIV MSM DEPT R AVERILL 3515 EB EAST LANSING MI 48824-1226

NO. OF COPIES	ORGANIZATION
1	UNIV OF WYOMING D ADAMS PO BOX 3295 LARAMIE WY 82071
2	PENN STATE UNIV R MCNITT C BAKIS 212 EARTH ENGR SCIENCES BLDG UNIVERSITY PARK PA 16802
1	PENN STATE UNIV R S ENGEL 245 HAMMOND BLDG UNIVERSITY PARK PA 16801
1	PURDUE UNIV SCHOOL OF AERO & ASTRO C T SUN W LAFAYETTE IN 47907-1282
1	STANFORD UNIV DEPT OF AERONAUTICS & AEROBALLISTICS S TSAI DURANT BLDG STANFORD CA 94305
1	UNIV OF MAINE ADV STR & COMP LAB R LOPEZ ANIDO 5793 AEWC BLDG ORONO ME 04469-5793
1	JOHNS HOPKINS UNIV APPLIED PHYSICS LAB P WIENHOLD 11100 JOHNS HOPKINS RD LAUREL MD 20723-6099
1	UNIV OF DAYTON J M WHITNEY COLLEGE PARK AVE DAYTON OH 45469-0240
1	NORTH CAROLINA STATE UNIV CIVIL ENGINEERING DEPT W RASDORF PO BOX 7908 RALEIGH NC 27696-7908

NO. OF COPIES	ORGANIZATION
5	UNIV OF DELAWARE CTR FOR COMPOSITE MTRLS J GILLESPIE M SANTARE S YARLAGADDA S ADVANI D HEIDER 201 SPENCER LABORATORY NEWARK DE 19716
1	DEPT OF MATERIALS SCIENCE & ENGINEERING UNIVERSITY OF ILLINOIS AT URBANA CHAMPAIGN J ECONOMY 1304 WEST GREEN ST 115B URBANA IL 61801
1	UNIV OF MARYLAND DEPT OF AEROSPACE ENGNRNG A J VIZZINI COLLEGE PARK MD 20742
1	DREXEL UNIV A S D WANG 32ND & CHESTNUT ST PHILADELPHIA PA 19104
3	UNIV OF TEXAS AT AUSTIN CTR FOR ELECTROMECHANICS J PRICE A WALLS J KITZMILLER 10100 BURNET RD AUSTIN TX 78758-4497
3	VA POLYTECHNICAL INST & STATE UNIV DEPT OF ESM M W HYER K REIFSNIDER R JONES BLACKSBURG VA 24061-0219
1	SOUTHWEST RSCH INST ENGR & MATL SCIENCES DIV J RIEGEL 6220 CULEBRA RD PO DRAWER 28510 SAN ANTONIO TX 78228-0510

NO. OF COPIES	ORGANIZATION
	ABERDEEN PROVING GROUND
1	US ARMY MATERIEL SYSTEMS ANALYSIS ACTIVITY P DIETZ 392 HOPKINS RD AMXSY TD APG MD 21005-5071
1	US ARMY ATC W C FRAZER CSTE DTC AT AC I 400 COLLERAN RD APG MD 21005-5059
1	DIRECTOR US ARMY RESEARCH LAB AMSRL OP AP L APG MD 21005-5066
85	DIR USARL AMSRL CI AMSRL CI S A MARK AMSRL CS IO FI M ADAMSON AMSRL SL BA AMSRL SL BL D BELY R HENRY AMSRL SL BG AMSRL SL I AMSRL WM J SMITH AMSRL WM B A HORST AMSRL WM BA D LYON AMSRL WM BC P PLOSTINS J NEWILL S WILKERSON A ZIELINSKI AMSRL WM BD B FORCH R FIFER R PESCE RODRIGUEZ B RICE AMSRL WM BE C LEVERITT AMSRL WM BF J LACETERA

NO. OF COPIES	ORGANIZATION

ABERDEEN PROVING GROUND (CONT)

AMSRL WM BR
C SHOEMAKER
J BORNSTEIN
AMSRL WM M
D VIECHNICKI
G HAGNAUER
J MCCAULEY
AMSRL WM MA
L GHIORSE
S MCKNIGHT
AMSRL WM MB
B FINK
J BENDER
T BOGETTI
R BOSSOLI
L BURTON
K BOYD
S CORNELISON
P DEHMER
R DOOLEY
W DRYSDALE
G GAZONAS
S GHIORSE
D GRANVILLE
D HOPKINS
C HOPPEL
D HENRY
R KASTE
M KLUSEWITZ
M LEADORE
R LIEB
E RIGAS
J SANDS
D SPAGNUOLO
W SPURGEON
J TZENG
E WETZEL
AMRSL WM MC
J BEATTY
E CHIN
J MONTGOMERY
A WERECZCAK
J LASALVIA
J WELLS
AMSRL WM MD
W ROY
S WALSH
AMSRL WM T
B BURNS
M ZOLTOSKI

NO. OF COPIES	ORGANIZATION

ABERDEEN PROVING GROUND (CONT)

AMSRL WM TA
W GILLICH
T HAVEL
J RUNYEON
M BURKINS
E HORWATH
B GOOCH
W BRUCHEY
M NORMANDIA
AMRSL WM TB
D KOOKER
P BAKER
AMSRL WM TC
R COATES
AMSRL WM TD
A DAS GUPTA
T HADUCH
T MOYNIHAN
F GREGORY
M RAFTENBERG
M BOTELER
T WEERASOORIYA
D DANDEKAR
AMSRL WM TE
A NIILER
J POWELL

NO. OF COPIES	ORGANIZATION
1	LTD R MARTIN MERL TAMWORTH RD HERTFORD SG13 7DG UK
1	SMC SCOTLAND P W LAY DERA ROSYTH ROSYTH ROYAL DOCKYARD DUNFERMLINE FIFE KY 11 2XR UK
1	CIVIL AVIATION ADMINSTRATION T GOTTESMAN PO BOX 8 BEN GURION INTERNL AIRPORT LOD 70150 ISRAEL
1	AEROSPATIALE S ANDRE A BTE CC RTE MD132 316 ROUTE DE BAYONNE TOULOUSE 31060 FRANCE
1	DRA FORT HALSTEAD P N JONES SEVEN OAKS KENT TN 147BP UK
1	DEFENSE RESEARCH ESTAB VALCARTIER F LESAGE COURCELETTE QUEBEC COA IRO CANADA
1	SWISS FEDERAL ARMAMENTS WKS W LANZ ALLMENDSTRASSE 86 3602 THUN SWITZERLAND

NO. OF COPIES	ORGANIZATION
1	DYNAMEC RESEARCH AB AKE PERSSON BOX 201 SE 151 23 SODERTALJE SWEDEN
1	ISRAEL INST OF TECHNOLOGY S BODNER FACULTY OF MECHANICAL ENGR HAIFA 3200 ISRAEL
1	DSTO WEAPONS SYSTEMS DIVISION N BURMAN RLLWS SALISBURY SOUTH AUSTRALIA 5108 AUSTRALIA
1	DEF RES ESTABLISHMENT VALCARTIER A DUPUIS 2459 BOULEVARD PIE XI NORTH VALCARTIER QUEBEC CANADA PO BOX 8800 COURCELETTE GOA IRO QUEBEC CANADA
1	INSTITUT FRANCO ALLEMAND DE RECHERCHES DE SAINT LOUIS DE M GIRAUD 5 RUE DU GENERAL CASSAGNOU BOITE POSTALE 34 F 68301 SAINT LOUIS CEDEX FRANCE
1	ECOLE POLYTECH J MANSON DMX LTC CH 1015 LAUSANNE SWITZERLAND

NO. OF COPIES	ORGANIZATION
1	TNO DEFENSE RESEARCH R IJSSELSTEIN ACCOUNT DIRECTOR R&D ARMEE PO BOX 6006 2600 JA DELFT THE NETHERLANDS
2	FOA NATL DEFENSE RESEARCH ESTAB DIR DEPT OF WEAPONS & PROTECTION B JANZON R HOLMLIN S 172 90 STOCKHOLM SWEDEN
2	DEFENSE TECH & PROC AGENCY GROUND I CREWTHER GENERAL HERZOG HAUS 3602 THUN SWITZERLAND
1	MINISTRY OF DEFENCE RAFAEL ARMAMENT DEVELOPMENT AUTH M MAYSELESS PO BOX 2250 HAIFA 31021 ISRAEL
1	TNO DEFENSE RESEARCH I H PASMAN POSTBUS 6006 2600 JA DELFT THE NETHERLANDS
1	B HIRSCH TACHKEMONY ST 6 NETAMUA 42611 ISRAEL
1	DEUTSCHE AEROSPACE AG DYNAMICS SYSTEMS M HELD PO BOX 1340 D 86523 SCHROBENHAUSEN GERMANY

REPORT DOCUMENTATION PAGE	Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	June 2002	Final, November 2001 – February 2002

4. TITLE AND SUBTITLE
High-Strain Rate Mechanical Response of Green Insensitive Munitions Gun Propellants

5. FUNDING NUMBERS
1L161102AH43

6. AUTHOR(S)
Michael G. Leadore

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Research Laboratory
ATTN: AMSRL-WM-MB
Aberdeen Proving Ground, MD 21005-5069

8. PERFORMING ORGANIZATION REPORT NUMBER
ARL-TR-2755

9. SPONSORING/MONITORING AGENCY NAMES(S) AND ADDRESS(ES)

10.SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT(Maximum 200 words)
Four lots of green insensitive munitions gun propellants were tested in uniaxial compression. A production lot of M14 that is currently used in the M865 training round was also tested for comparison purposes. The materials were tested while conditioned at 21°, 63°, and −32 °C. The materials were taken to ~60% strain using a deformation rate of 1.3 m/s. The stress at failure, strain at failure, compressive modulus, failure modulus, incremental energy density, and the fracture assessment values were recorded for each test.

14. SUBJECT TERMS
high-rate deformation, green insensitive munitions, mechanical properties, gun propellants, material testing system, uniaxial compression, modulus, fracture

15. NUMBER OF PAGES
29

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18 298-102

INTENTIONALLY LEFT BLANK.